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Application of Deep-hole Pre-cracking Blasting in the Preserved Roadway beside the Gob for Working Gaolin in Coal Seams

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Abstract

In working Gaolin in the Suoli Mine of Huaibei Area, the roof strata of the gob approaches the working face to a great extent, offering difficulties for ventilation and pedestrian. To solve the problem, experiments are carried out by the haulage way of the working face by drilling upward a series of holes in the roof of the wall to be worked for deep-hole pre-cracking blasting so that a cracked surface is formed between the roof of the haulage way and the roof of the working area. In this way, the problem is solved which is attributable to the great approaching movement of the rock strata in the roof and the floor of the gob. Careful observation shows that with the blasting carried out, the pre-supporting resistance and the approaching movement of the rock strata of the roof and floor of the haulage way are not significantly varied. And in the area behind the working face, the rock strata approaching movement is apparently reduced.

Keywords: deep-hole pre-cracking blasting; roadway along the gob; top breaking pressure relief; roof and floor approaching movement

1. Introduction

The Suoli Mine of Huaibei Area is rich in Gaolin coal seams, which is of great economic significance. By utilizing existing mining facilities, the mine succeeded in working Gaolin by retreat mining [1.2]. With the expansion of production, they find that working in the same mining zone, problems are increasingly appearing when it is difficult for one process to succeed another. In addition, it takes a long period of time for miners to prepare roadways, and tunneling advances rather slowly along the caved roadway. Faced with the above-mentioned problems, the mine carries out experiments by preparing a roadway along the

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gob in the haulage way. The experiment shows that when they use anchoring rods in combination with beams and grids as supports, wood piles as supporting structure by roadways and double lift sheds along the strive, it will be easy to retrieve the supporting materials. However, a great approaching movement of the roof and floor strata in and great deformation of the roadway of the gob will be witnessed, offering difficulties for the ventilation and pedestrian in the next working section. Therefore, the great approaching movement of the roof and floor strata has become an urgent problem to be resolved.

Domestically, coal mines usually adopt the top-breaking pressure-relief method [3] to solve the problem. With the application of the method, the pressure in the haulage way and return airway is apparently reduced and so are damages to the roadways. In this case, normal production and safety are both ensured. And deep-hole pre-cracking blasting helps top-breaking pressure-relief to a great extent [4].

2. Pre-cracking blasting

Based on smooth blasting, pre-cracking blasting develops as a controlled blasting technique. And it is mainly used for underground and open-pit mining. By pre-cracking blasting, they mean that before the caving blasting is implemented in the working face, a number of blasting holes are drilled in accordance with the pre-designed contour surface for the purpose of separation of the working face from the rock in the preserved area.

2.1 Choice of parameters for pre-cracking blasting

The methods currently available for the choice of parameters for pre-cracking blasting [5-7] are theoretical deduction, direct experimentation, experience-based analogy, modeling experimentation and so on. An alternative is that by taking into consideration the project performance and working experiences, such parameters as the diameter of the blasting hole, the distance between holes, the minimal resistance line, the non-coupling co-efficient, the intensity by which the explosive rolls are bound onto the detonating cord, etc. can also be chosen.

(1) Suppose the pressure on the wall of the blasting hole [8] is p , then in blasting, for the wall not to be crushed into pieces, Formula (1) should be satisfied.

$$p \le \sigma_{c\max} \tag{1}$$

However, micro-cracks should be formed around the blasting hole so that pre-cracks can be formed. For that sake, Formula (2) should be satisfied:

$$p_2 \ge \sigma_{tt\max} \tag{2}$$

Where p stands for the pressure on the hole wall (MPa);

p_2 stands for shock pressure (MPa);

$\sigma_{c\max}$ stands for the ultimate compressive strength of the rock (MPa);

$\sigma_{tt\max}$ stands for the ultimate ultimate tensile strength of the rock, generally 1.3-1.5 times the tensile strength (MPa).

(2) Suppose the intensity for explosive rolls bound onto the detonating cord [9] is q_1 ,

$$q_1 = \frac{\pi R^2 q_v}{1000} = \frac{\pi R^2 \rho_0}{1000 K_V^2} \tag{3}$$

Where q_1 stands for the intensity for explosive rolls bound onto the detonating cord (g/m);
R stands for the radius of the hole (mm);
q_v stands for the explosive roll binding intensity per cubic unit (g/cm^3);
ρ_0 stands for the explosive roll binding intensity (g/cm^3)
Kv stands for the non-coupling coefficient.

(3) Suppose the distance between holes [10] is a . Then when the rock begins to break, a stress field is formed around the hole. Consequently, by turning to the theory of elasticity, we will have:

$$\begin{cases} \sigma_r = \dfrac{-P\, r^2}{l^2} \\ \sigma_\theta = \dfrac{P\, r^2}{l^2} \end{cases} \quad (l \geq r) \tag{4}$$

When σ_θ exceeds the ultimate tensile strength, the rock will experience damaging micro-cracking. But when $\sigma_\theta < \sigma_{tt\max}$, cracks will stop developing. Therefore, the radius of the preliminary crack in the hole r_a will be:

$$r_a = \sqrt{\frac{P}{\sigma_{tt\max}}}\, l \tag{5}$$

When the preliminary micro-crack is formed, it will further develop under the static pressure P_1 . Then for the micro-crack to develop into a through-crack, the conditions are as follows:

$$P_1 \cdot 2r = (a - 2r_a)\sigma_{tt\max} \tag{6}$$

$$a = 2r_a + \frac{2P_1 r}{\sigma_{tt\max}} = 2r\sqrt{\frac{P}{\sigma_{tt\max}}} + \frac{2P_1 r}{\sigma_{tt\max}} \tag{7}$$

Where r stands for the radius of the hole (mm)
P stands for the actually pressure on the hole wall (MPa);
P_1 stands for the static pressure in the hole (MPa).

Then from the above formulae, the hole-spacing distance a can be derived at.

In addition to choosing pre-cracking blasting parameters by theoretical calculation, we have to turn to experience for induction and summary so that the results will be complementary and mutually beneficial. Then the parameters chosen will be more practical and the pre-cracking blasting will give the desired results.

2.2 Choice of hole-diameter and type of explosive

Generally speaking, the diameter of the hole is determined by the project quality and requirements to reach such quality. In addition, the existing facilities should also be taken into consideration. It is a rule that the shorter the diameter of the hole, the less the drilling damage to the rock strata. Consequently, the more frequently the drilling traces are witnessed and the more easily for the contour of the pre-cracked surface to be brought under control, and the vise versa. We also know that the shorter the diameter of the hole, the more difficult for hole-drilling and explosive filling. Therefore, usually d=38～l00mm is preferable.

2.3 Mode for explosive roll placing and length of blockage

The explosive rolls are usually placed either with or without intervals. Placing explosive rolls with intervals refers to binding explosive rolls onto the detonating cord each at a distance from another. Then by using the detonating cord, all the explosive rolls will be exploded. And so, the mood of placing explosive rolls is currently preferred. However, placing explosive rolls without intervals is rather desirable for pre-cracking blasting. From theoretical deduction, we know that when the explosive roll binding intensity is determined, the more evenly distributed the rolls, the better. However, owing to the fact that there is a great clamping force at the bottom of the hole, it will be not easy for micro-cracks to develop into cracks. Therefore, the intensity for the explosive roll placing at the bottom of the hole should be doubled.

2.4 Engineering practice of deep-hole pre-cracking blasting

The working face chosen for the experiment consists from upside down of a seam of Gaolin 3.92 meters thick, a seam of aluminum containing mudstone 2.42 meters thick, a seam of silt mudstone 2.53 meters thick, a seam of carbonaceous mudstone 2.45 meters thick and a seam of sandy mudstone 2.55 meters thick.

The haulage way for the working face chosen for the experiment is 1 meter wider than the haulage way of the working face above it so that the wood pile and wood shed lift as filling can be placed where the above working face has not overlapped the working face chosen for the experiment.

The pre-cracking blasting is conducted in the aluminum containing mudstone seam and the silt mudstone seam above the Gaolin seam. Since the Goalin seam is worked by breaking a layer on its top 0.8 meters in thickness, the hole is drilled 5.73 meters in depth. To eliminate damages the pre-cracking blasting does to the rock strata in the immediate roof directly above the preserved roadway, such damage is prevented from occurring in the immediate roof of the preserved roadway. To facilitate the downward movement of the cut rock, the blasting-hole slants toward the gob by an angle of about 70^{o}. Cracks develop in the 2.42 meter thick aluminum seam and the 2.53 meter thick silt mudstone seam. And calculation shows that the blasting hole runs about 6 meters long. The layout of the haulage way, the wood pile together with the wood shed lift and the blasting hole are illustrated as follows.

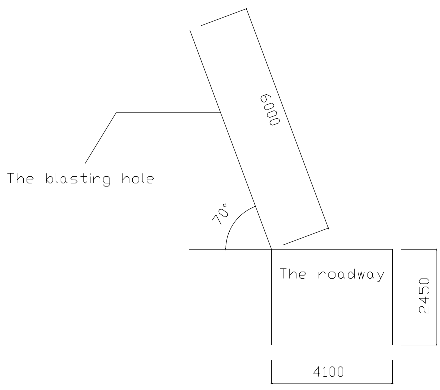

Fig 1 An illustrated figure for deep-hole pre-cracking blasting in the roof of the preserved roadway by the gob

The hole is drilled by the anchoring rig and instantaneous mining detonators and detonating cords are used. The cords are connected in series and initiators of KB-200 type are used to initiate the blasting. Before blasting, 1 meter of the hole is kept for binding detonators with detonating cords. Double detonators and double detonating cords are used for initiating, and lute is used for sealing. Each group consists of 6 holes and the explosive rolls filled in the hole will explode simultaneously. Hole-drilling, hole-charging, hole-sealing and the like jobs are completed in advance. On the completion of the above mentioned jobs, we will check the holes one by one and record, for each numbered hole, the depth of the hole, the length of the explosive roll, the sealing soil and the blasting lute. How many explosive rolls and how much sealing soil are used for each hole are recorded by turning to detonating cords and wood filling rods as references so as to ensure explosive columns are each closely connected with another. In addition, the work should be done to prevent explosive columns and sealing soil from sliding downward. The hole is charged and soil-sealed until the filling reaches the point 3meters from the mouth of the hole. Then detonators and detonating cords are connected and the holes are blasted once for all. To prevent explosive rolls from sliding downward in the process of charging, specially designed check sheets are placed in the hole so that hole-charging and sealing are facilitated.

To make better use of blasting energy, air columns are placed as separators, since they can improve the matching in blasting energy spreading. In this way, the preliminary pressure the blasting brings about on the hole-wall will be reduced and the pulse produced by blasting is regulated by reducing the preliminary peak and by extending the lasting duration of the blasting pulse so as to raise the energy utilization efficiency of blasting. In addition, part of blasting energy is kept in the air so that the time is prolonged for blasting to affect rock strata. Consequently, blasting energy will be evenly distributed throughout the hole. In this way, blasting energy is well utilized and blasting quality is much improved.

The parameters for blasting are as follows: hole-depth=6m; inclination angle=70^o; hole-diameter=45mm; hole-spacing distance=0.8m; diameter of explosive roll=35mm; explosive for a single hole=1.8lg; and sealing length=3.0m. To maximize blasting effects, the 3rd class mining explosive of PT-473 type is chosen. And in accordance with the characteristics of rock strata, the air separation column of 300～350 mm is used.

3. Observation and analysis of resistance to advance supporting and rock deformation after pre-cracking blasting

The layout of the working face under experiment is not different from that of the working face above it. The production is carried out in a single cycle and the daily cycling advance is 1.0m. The working mode is that two cycling processes are intervened by a preparing process. The roof of the working face is supported by the DZ25 single pillar. The row spacing distance is 1000mm and the pillar spacing distance is 600mm. To obtain some knowledge of how pre-cracking blasting in the preserved roadway for the working face under experiment exercises impacts on mine pressure and deformation, the experiment is monitored in site with regard to the pressure in advance in the haulage way, and the roof and floor deformation of the haulage way and the preserved roadway along the gob.

3.1 Experiments on resistance to advance supporting in haulage way

The advance supporting for the working face in the haulage way is 10m in length and the support consists of the DZ single hydraulic pillar and the HDJA1000 hinged roof beam. From the working face, at every point 1m away, the working resistance to the advance single supporting pillar is measured and the average value of the resistance is listed in Table 1.

Table 1 Average resistance to single advance supporting pillar in haulage way for working face

Distance from working face (m)	1	2	3	4	5	6	7	8	9	10
Supporting resistance (MPa)	20	20	17	17	15	9	9	8.5	8	8

The maximal value of the advance supporting resistance for the working face above it is 21 MPa. From Table 1 we know that compared with the working face above it, the working face under experiment is not much different in supporting resistance value and value variations are governed basically by same laws.

3.2 Rock deformation in haulage way

According to the on-spot observation records, the approaching movement value at the observation point where the rock wall is 10m away from the haulage way is deduced. Then values for observation points along the course of advance are deduced and shown in Table 2.

Table 2 Roof and floor rock stratum approaching movements observed at points 1-10m away from working face under experiment

Advance（*m*）	1	2	3	4	5	6	7	8	9	10	Total
Roof and floor approaching extent（*mm*）	5	5	6	12	37	69	126	85	67	8	420

The approaching movement values observed at the points 1-10m away from the working face above the working face under experiment are 400mm in sum. And from Table 2, we know that the approaching movement values observed at the points 1-10m away from the working face under experiment are 420mm in total, indicating that the approaching movement values for the two working faces are not significantly different.

3.3 Rock deformation at observation points behind the working face

When roadside supports are placed, in the gob behind the working face, the roof and floor approaching movement values at various points are listed in Table 3.

Table 3 The roof and floor approaching movement values as functions of times.

Time（*d*）	1	2	3	4	5	6	7	8	9	10
Approaching extent（*mm*）	50	95	150	200	220	240	252	268	271	273

From Table 3, we know that when the working face is deserted for 10 days, the roof and floor approaching movement is up to 273mm only and with the approaching movement in front of the working face of 420mm, the total approaching movement will be 700mm, apparently less that the approaching movement of 1200mm for the working face above it. And it is mainly the roof and floor rock stratum movement behind the working face that is cut into.

3.4 Analysis of resistance to advance supporting and rock deformation after pre-cracking blasting

After pre-cracking blasting, the rock strata in front of the working face will bear the pressure brought about by Gaolin working. Owing to the fact that the rock strata are only under pressure, the surface with pre-cracks slating in an angle of 70^o will not affect the spreading of the pressure. Therefore, compared with when the blasting was not carried out, the supporting resistance in the haulage way in front of the working face and the roof and floor stratum approaching movement are little affected.

When it comes to the preserved roadway, after deep-hole pre-cracking blasting, a weak surface is formed between the immediate roof of the preserved roadway and that of the gob. In the places behind the working face, the immediate roof will be caved into the gob along the blasting-induced cracks. The roof of the gob will break along the edge of the crack so that the roof strata for the preserved roadway will form a cantilever of the same width as the width of the preserved roadway. Compared with when the blasting was not carried out, the arm of the cantilever is shortened with deformation resistance increased. Therefore, the roof and floor rock stratum approaching movement in the preserved roadway is greatly reduced.

4. Conclusion

When deep-hole pre-cracking blasting is applied in the roof of haulage way, a weak plane will be formed between the immediate roof of the preserved roadway and that of the gob. In that case, compared with the state before the blasting, less resistance is witnessed to the advance supporting in the haulage way and the approaching movements of the roof and the floor exercise less impact on rock strata. Then rock stratum movements in the roof and the floor of the preserved roadway behind the gob are evidently reduced, beneficial to the stability of the preserved roadway, ventilation and safe production, hence significant to working Gaolin in coal seams.

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